Engineering Narrative

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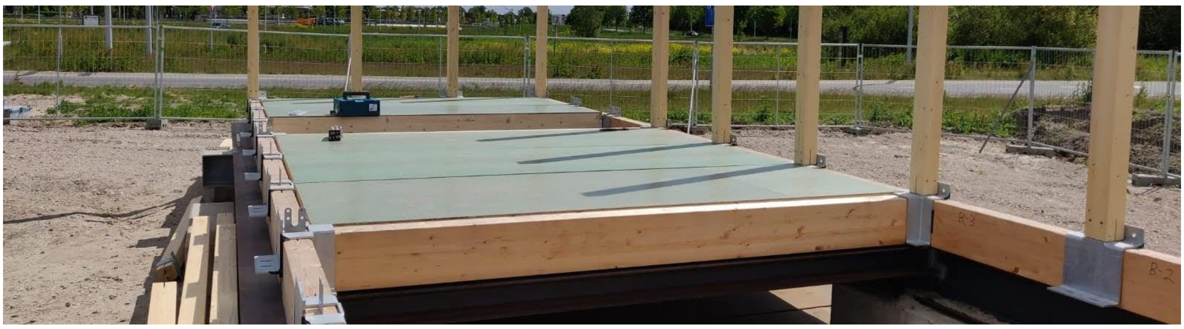
1 Structural system

1.1 Suteki frame

Celcius distinguishes itself by it's simple yet strong structural frame. The goal was to shorten the construction time by simplifying the building method. This would enable average non-technical-educated people to construct the structural frame with ease. To reach this goal we chose a prefabricated system that lines up with our modular concept while also meeting the circular ambitions. That's why we have chosen to incorporate the Suteki frame into our house.

The structural frame of the Celcius house is designed and made by Suteki Wood Systems, a company originally from Japan. This system consists of PEFC-labelled, laminated and pre-cut timber beams(280x120mm) and columns (120x120mm) and a simple and logical carbon cast steel connection principle. Allowing the Suteki system to be built up using only a hammer.

The connectors and pins are large and easy to handle. The construction process of a Suteki systems goes without saying. The pins fit perfectly into the pre-drilled holes that line up with the connectors inside the columns. This has a significant impact on the construction time by shortening the time it takes to built up the structural frame. The pins and connectors can be easily taken apart making it a perfect choice for our modular building concept. This also allows users to add more beams and columns enlarging their house with ease.



1.2 Brackets

Traditional speaking, the building envelope will be attached to the structural frame using screws and bolts. This will over time degrade materials and it isn't as modular as we would like it to be. Using screws and bolts would mean that we would have to drill holes into our wood which damages the material, making it hard to reuse. This had to be tackled in order to meet our circular ambitions.

The Celcius house has a trick up its sleeve to tackle this problem. It uses an state of the art one of a kind connection method. It consist of the so-called brackets that slide over the beams and columns without damaging them. Since the brackets don't have to be bolted together the materials won't get damaged. The brackets enable builders to attach the panels against the structural system by using pre-applied connectors that will align perfectly with the brackets. That way the building envelope can be attached without damaging any materials boosting the circularity of our concept greatly.

2 Mechanical system

2.1 HVAC-design

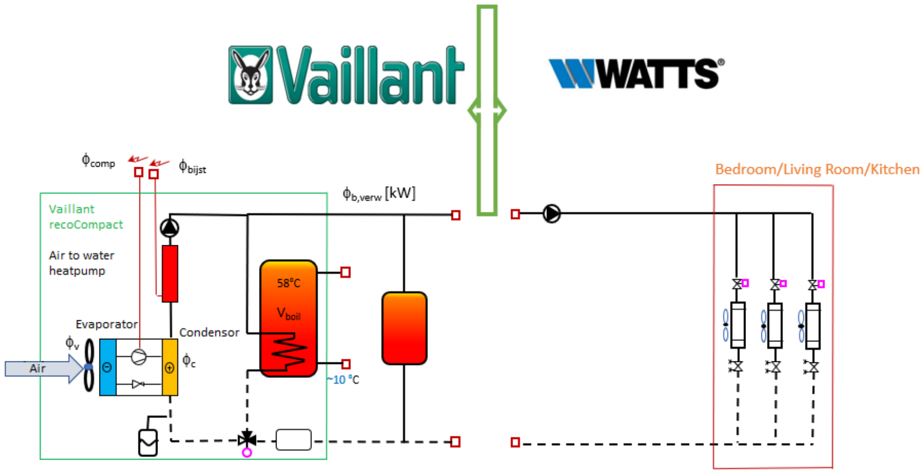


Figure 1 Heating/cooling circuit diagram

The Celcius house has a state of the art integrated heating, ventilation and air-conditioning system. The system consist of a modern heat pump, with integrated ventilation and heat recovery capability. Made in Remscheid, Germany by Vaillant. The generated heat is distributed via modern convector radiators which are placed on the ceiling of the rooms. The radiators are made in Eerbeek, Belgium by Jaga. Our system also give the residents the option to individually regulate the different room temperatures, via the Watts Heating control unit. In the following paragraphs we will elaborate about more aspects of this modern HVAC-system.

2.1.1 Vaillant RecoCOMPACT, heatpump

Figure 2 the Vaillant recoCOMPACT heatpump

The Netherlands has a broad natural gas network. At least 91% of all buildings are connected to the gas network. However the Dutch government has the goal to go carbon neutral by 2050. Therefore the built environment needs to redesign their way of generating heat. The Celcius team also felt that need and sought for a modern way to generate heat.

The solution for sustainable, modular and efficient heat production would be a heat pump. The Vaillant company in Germany had such a solution. Their recoCOMPACT checked our boxes. The system generates heat and cooling via an air to water inverter. Without an outside inverter, but extracts the air via rosters on the outside of the house. It can store up to 211 litres (55.7 gal.) of sanitary water at 53˚ Celsius (127.4˚ Fahrenheit). Therefore suitable for a family of four. The system is modular and connects easily with a second boiler tank. The recoCOMPACT has an integrated ventilation and heat recovery system.

2.1.2 Watts and Jaga beams, the new way of heating and cooling

The distribution of heating or cooling is via the Watts climate control unit. This gives the residents the opportunity to individually regulate the room temperatures. In Celcius house we can regulate the bedroom and combined living space individually. The unit also gives the option to expand to more radiators or rooms. Just as expandable as the house itself.

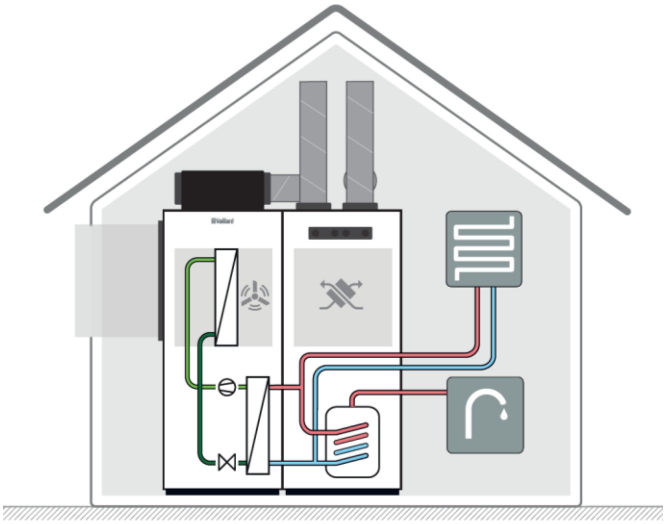
Figure 3 The Watts climate control unit

Figure 4 Jaga Briza in the bedroom

The combined living space and the bedroom are heated/ cooled by fan coil convector radiators. These radiators are called Briza's, made by Jaga. Due to the integrated fan coils these radiators are capable of heating or cooling in a short amount of time. The bathroom is 'heated' by an infrared panel. By only turning the infrared panel on when the room is used we make efficiently use of the limited energy.

2.1.3 Ventilation

A ventilation and heat recovery system is integrated in the house. To control the flow of fresh air and control the humidity level. Both the ventilation and heat recovery system are part of the Vaillant recoCOMPACT. Which saves space and makes the system more efficient. The needed ventilation capacity is 150 m^3/hour. The capacity of the Vaillant recoCOMPACT is 260 m^3/hour. Therefore additional rooms or needed ventilation capacity is available with the current system. The heat recovery system limits the heat loss due to ventilation to a minimum.



3 Electrical system

3.1 Energy distribution design

The Celcius implemented state of the art innovations in the house. All the innovations, such as the heat pump, fan coil radiators, modern kitchen appliances. These use electric energy, and lots of it. Due to the high intensity of energy use the distribution design needs to come by the demand. Therefore the Celcius house has an extensive electrical control box unit. With 13 fuse groups. The circuit diagram can be found in the document 'Final drawings'.

3.2 Energy consumption

The energy consumption of the Celcius house is, just as the electrical control box, extensive. The house uses on average 21 kWh per day. Annual average is 7741 kWh.

Celcius house energy consumption	Power kWh per cycle	Times used per week	Power use kWh/week	Power kWh/day (in use)
Technical room				
Heat pump	*continuous*	*continuous*	23,93	3,42
Ventilation	*continuous*	*continuous*	6,51	0,93
Car charger	5	7	35	5
Miscellaneous	*continuous*	*continuous*	6,37	0,91
Kitchen				
Siemens combi fridge	0,75	7	5,24	0,75
Siemens washing machine	0,65	4	2,60	0,37
Siemens dishwasher	0,73	5	3,65	0,52
Siemens cooking plate	1,15	6	6,90	0,99
Siemens cooker hood	0,11	6	0,66	0,09
Siemens oven/microwave	1,70	4	6,80	0,97
Bathroom				
Miscellaneous	*continuous*	*continuous*	2,35	0,34
Shower	0,25	10	2,45	0,35
Toilet	0,37	7	2,56	0,37
Lighting	*continuous*	*continuous*	2,21	0,32
Standby mode margin	*continuous*	*continuous*	24,36	3,48
GPO and small appliances	*continuous*	*continuous*	16,80	2,4
		Total:	**148kWh** *per week*	**21kWh** *per day*

3.3 Energy storage

The photovoltaic panels produce during peak hours 7 kW. The excess power needs to be stored and can be used later on the day. As durable batteries are larger in size and less modular. We used the LG Chem RESU7H. This battery pack can store up to 6.6 kWh of usable energy. The LG battery pack gives the option to expand the capacity via an modular system. The house is also connected to the grid, so we are also able to feed back to the grid or use from the grid when necessary.

4 Plumbing system

Water is used for all day to day tasks. Personal hygiene, cleaning, washing, cooking and doing the dishes are the biggest users of water. A house without water isn't a house. There is an abundance of water in the Netherlands. In lakes, rivers and in the ground. The main source of water is the ground. Municipal pumping stations pump up water and purify it to be drinkable.

4.1 Plumbing design

Water pipes

The house is modular and needed a modular plumbing system. Our sponsor Wavin introduced us to their pipework solutions. The Push-fit Hep2O is a modular and easily to connect an disconnect pipework solution. Which makes it easier to adapt the waterwork in case of house expansion. As well as the water supply as the heating system is fitted with this innovative solution. For the waterworks blue print of the house I refer to the Final Drawings.

Figure 5 Intersection of the Hep2O piping solution

Durability of appliances and pipework

Lime is present in drinking water which could clough up the waterpipes and moving parts in appliances. Lime also leaves stains on surfaces. Resulting in maintenance or in the worst case replacement of appliances or waterpipes. Therefore we took measures against the presence of lime in drinking water by installing a descaler. Watts Water Technology provided us the OneFlow water descaler. The OneFlow uses no electricity, needs no sand or salt and is low in maintenance. And works on the basis of TAC-technology.

4.2 Water usage

As years become dryer and dryer due to the climate crisis, water shortages are more common. Especially during summers with less rain. More and more people are becoming aware of there water use. And start using water more sparingly.

To do our part we used water innovations in our Celcius house. In the average house the shower is the largest consumer of water, with an average water use of 64 litres (16 US gallons) per shower use. Therefore we searched for an innovative shower, which use lesser water.

The Upfall Shower

The Upfall Shower is an innovation in showering. It uses a Upcylce shower system that recirculates the used water. Before recycling it the 'used' water is filtered with UV-filtration. Fresh and heated water is added each cycle. By reusing water, less water is used during showering. Resulting in only using 1.2 (excluding usage of 4.5 litres at start up) litres of water per minute instead of the conventional 6 litres. The Upfall Shower is integrated in the house because of the low water usage and innovative aspect.

Figure 6 The installed Upfall Shower

Water usage table

The average water usage of the house per day is 139.3 litres (37.7 US gallons) of drinking water. The Dutch average of water usage for two residents is 271.2 litres (71 US gallons) per day. A substantial difference with the water usage of the Celcius house. The specific water usage can be found in appendix 6.4.

5 Photovoltaic energy

5.1 PV-design

Because the Celcius house uses no natural gas we are depended on renewable energy. Photovoltaic energy production is the most obvious solution. Therefore we expedited the solutions. The Netherlands has an average of 1500/1550 hours of sun. So, to get sufficient energy the team decided to fill up the entire roof with PV-panels and add a ‘Zonneboom’. Dutch for solar tree. The panels needed to be as efficient as possible, therefore we chose JA Solar JAM60S10. These panels have an wat peak of 340.

The PV-panels on the roof were set up in an east to west orientation. Twelve PV-panels were laid in de western direction and twelve in eastern direction on a 15˚ tilt. Three panels are set up on a solar tree (not yet constructed) in the southern direction on a 15˚ tilt. We chose to use an east-west orientation due to the evenly spread upkeep during the day.

Figure 4 Van der Valk East-west orientation

Figure 8 The Sungrow inverter and fuse control box

Due to the fact that the system is grid connected but also uses battery storage we looked for a inverter which could manage the different inputs. Therefore we used the Sungrow SH10RT, which can seamlessly change from PV to battery or grid (including feeding back).

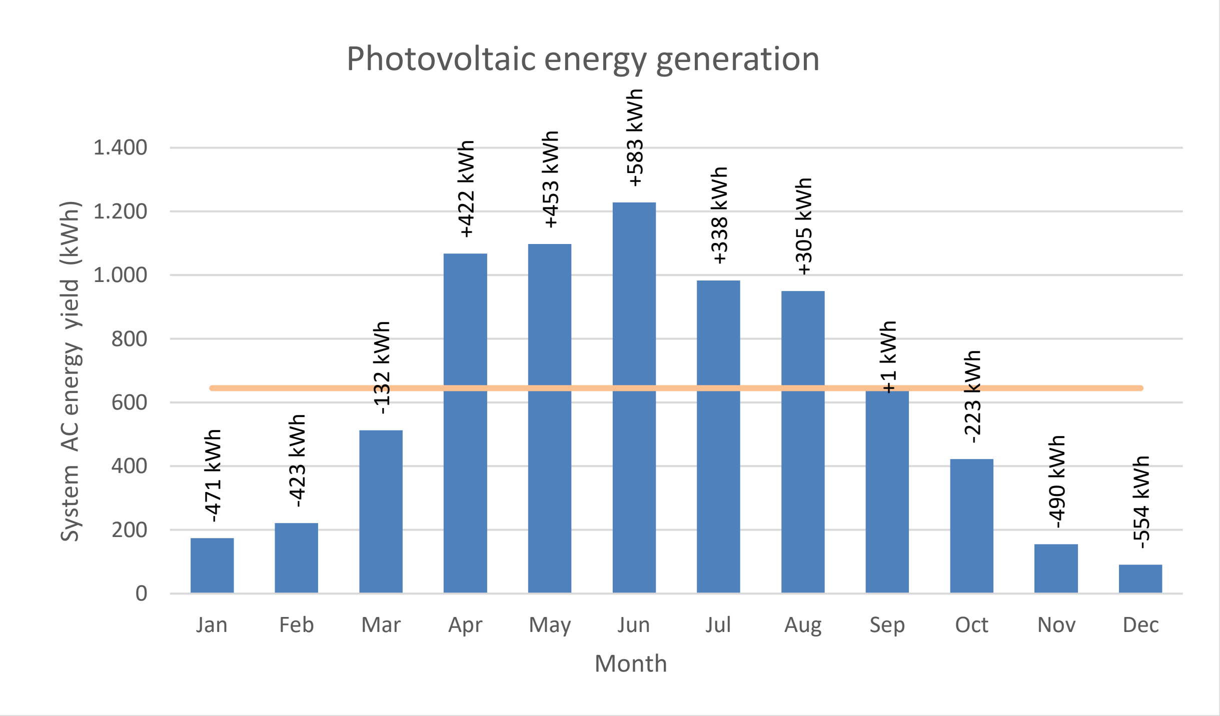
Figure 9 PV panels being installed

5.2 PV upkeep

The following calculations are done with the System Advisor Model from NREL. Documentation will be enclosed in the Dropbox ZIP-file.

Based on the following:
Location: Amersfoort, Netherlands
Coordinates: 52°09'18.0"N 5°24'07.2"E
Elevation: 7 meters
Base years: 2007- 2016
Weather information source: European Commission PV-GIS database

The annual upkeep of our PV installation is 7551.5 kWh. The annual energy consumption is 7741.7 kWh. Resulting in a deficit of -190 kWh per year. In the graph underneath the spread of the PV generation is visualised. Per month is visualised how much energy is generated and what de surplus or deficit is. As can be seen at the top of the charts. Further information can be found in the appendix. Such as: PV yield per hour, table of power usage vs PV yield and the PV system diagram (appendix 6.1 to 6.3).



Conclusion

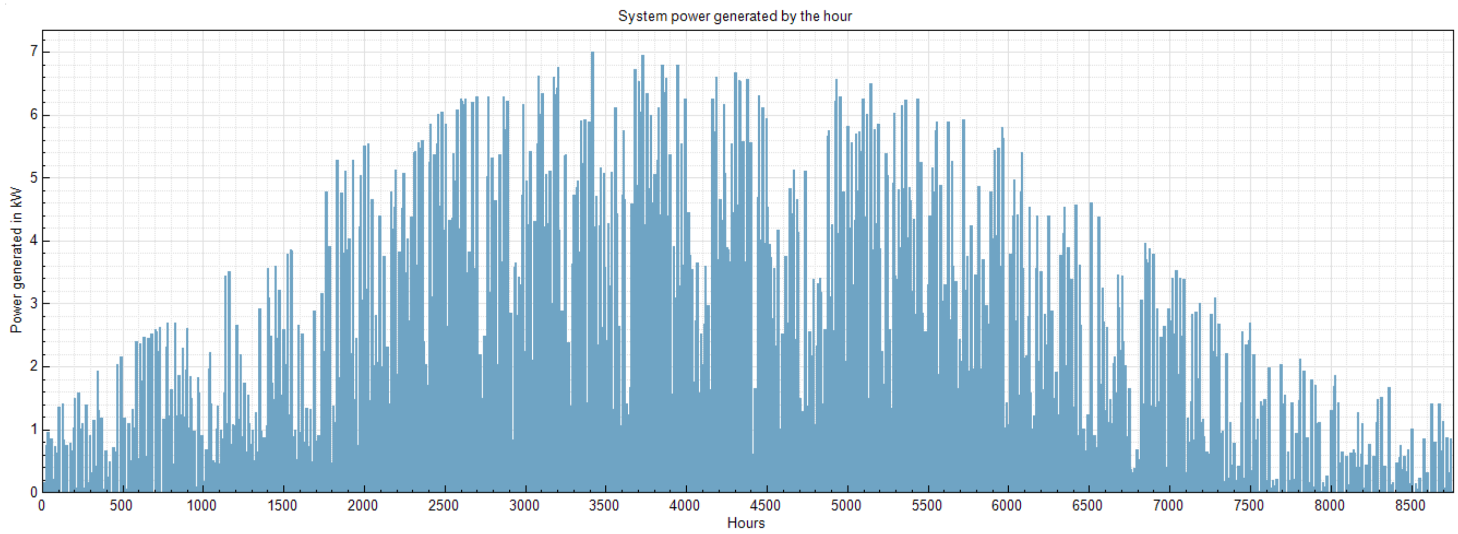
Overall we are a near Net-Zero Energy House. During the months April till August we are guaranteed self-sufficient in our energy demand. September is a doubtful case with a surplus of less than 1 kWh. October until March are the months were we rely on our net connection.

6 Appendix

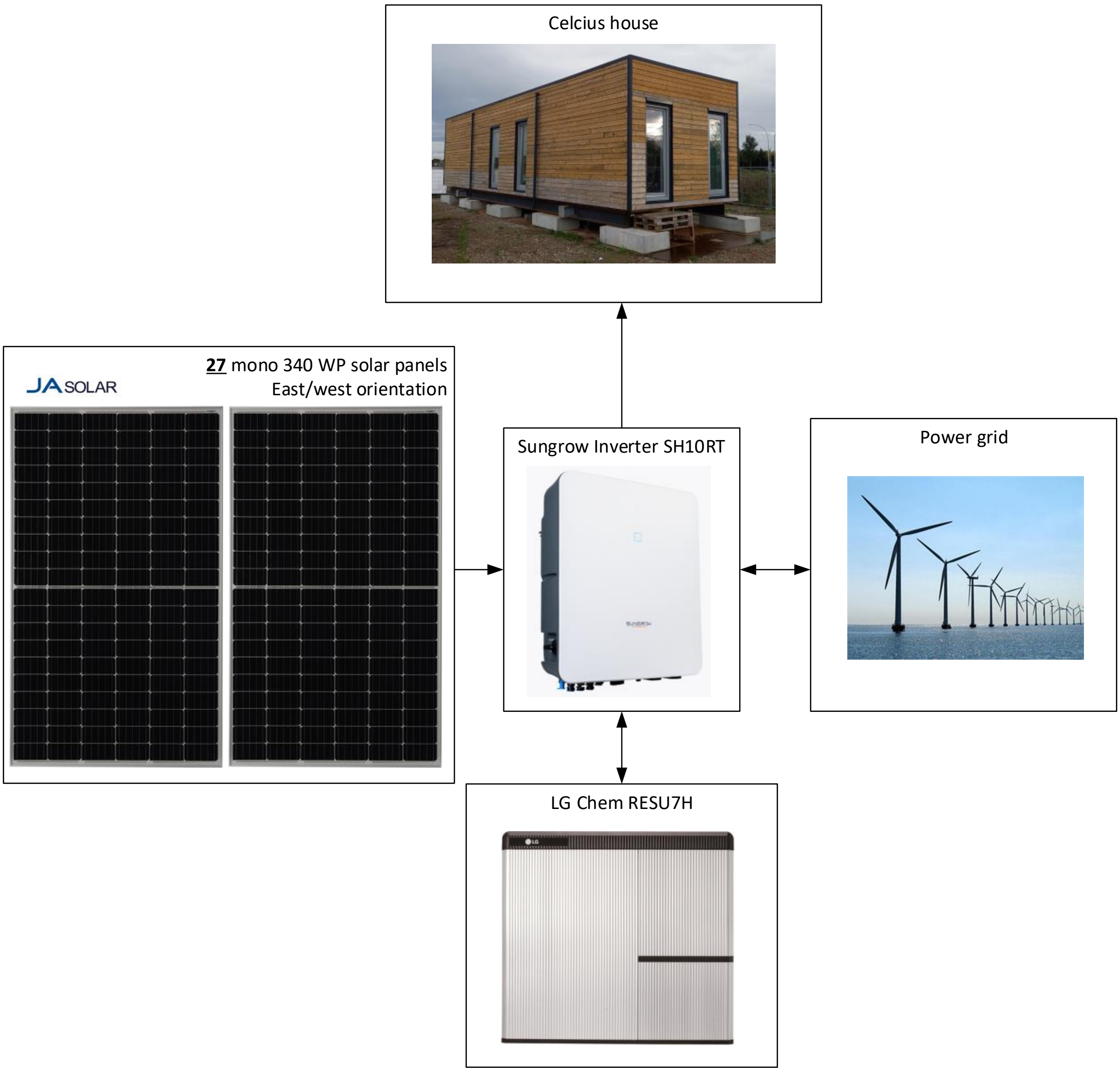
6.1 PV energy generation

Month	System AC energy | (kWh/mo)	Monthly average energy consumption	Deficit/surplus
Jan	174 kWh	645 kWh	-471 kWh
Feb	222 kWh	645 kWh	-423 kWh
Mar	513 kWh	645 kWh	-132 kWh
Apr	1068 kWh	645 kWh	+422 kWh
May	1098 kWh	645 kWh	+453 kWh
Jun	1228 kWh	645 kWh	+583 kWh
Jul	984 kWh	645 kWh	+338 kWh
Aug	950 kWh	645 kWh	+305 kWh
Sep	646 kWh	645 kWh	+1 kWh
Oct	423 kWh	645 kWh	-223 kWh
Nov	155 kWh	645 kWh	-490 kWh
Dec	91 kWh	645 kWh	-554 kWh
Annual total PV yield:	**7.551,5**	**Deficit:**	**-190 kWh**

6.2 System power generated in kW



6.3 PV system diagram



6.4 Water usage table

Water usage Celcius house

#	Water user	Usage per cycle (L)	Times used per day	Water usage in liters (day)(L)	Water usage in liters (week)(L)	Based on
1	Upfall Shower	14,1	1,5	21,2	148,1	8 minute shower, based on two residents
2	Siemens washing machine	52,7	0,6	31,8	222,5	Based on 220 washes per year
3	Siemens dishwasher	7,7	0,8	6,3	44,3	Based on the ECO washing program, 300 washes per year
4	Cooking	6,0	1,0	6,0	42,0	
5	Drinking	2,0	2,0	4,0	28,0	Based on two residents drinking at least 2 liters of waters per day.
6	Legionella prevention boiler	210,0	0,1	30,0	210,0	Weekly safety program boiler for prevention legionella bacteria
7	Toilet	3,0	8,0	24,0	168,0	Based two residents and 4 bathroom visits each
8	Personal hygiene	8,0	2,0	16,0	112,0	Based on two residents
			Totals:	**139,3**	**974,8**	